DEVELOPMENT AND APPLICATIONS OF TAIWAN BRIDGE MANAGEMENT SYSTEM

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ABSTRACT

Bridge management has become an important issue in the infrastructure construction in Taiwan which is located in an earthquake zone with many mountains and rivers. A comprehensive management information system for bridge maintenance has become a must. The Taiwan Bridge Management System (TBMS) was initially developed in 1999 and has been set online since 2000. Funded by the Institute of Transportation under the Ministry of Transportation & Communications, the T-BMS is a web-based system widely used by all of the bridge management agencies in Taiwan.

It has been a useful tool in bridge management and maintenance. Bridge data are readily accessible to. The latest version consists of eight functional modules: (1) Inventory; (2) Inspection; (3) Maintenance; (4) Statistics; (5) Decision Support; (6) Geographical Information System; (7) Precursory; and (8) Parameters Setting.

With an inventory of more than 28,000 bridges, T-BMS is heavily relied on for evaluating the performance of the bridge management agencies. Triggered by a fatal collapse of a major bridge due to a typhoon in central Taiwan in 2008, hundreds of bridges in unstable conditions are now under renovation or reconstruction.

T-BMS has accumulatively collected data which has brought about remarkable results and is expected to continually upgrade itself to carry out the mission to better bridge management and maintenance in Taiwan.

1. HOW COME THE SYSTEM?

Taiwan Bridge Management System（The System or TBMS）came into being, pursuant to a long-term development plan, which was tailored to suit her indigent environmental, climatical conditions. Different management systems with different compositions of functions bring about different deteriorations to different degrees.

There are various authorities that exercise control and management of bridges in Taiwan. Each has its share of responsibility and power. Limited by insufficient staff as well as professional deficiency, none was entrusted with full control of a bridge management job. That

is a case of “Everybody’s business is nobody’s business.” Defects are numerous, it is apparent.

So far as bridge management is concerned, bridge data were all kept in written form which was hard to upkeep in terms of space needed to store. It is hard to retrieve, in addition. As though that was not bad enough, data thus kept are vulnerable to natural disaster and human neglect leading to damage or loss.

It was aimed at warehousing system that integrates all in one, in a systematized and digitalized way. With all data in a single system, that will facilitate analysis. Such a system, if successfully developed and maintained, would be relied on for a competent bridge management.

There was once a time when various agencies set up their own management systems to satisfy their specific as well as general requirements such as Taiwan Area National Freeway Bureau, Taichung County Government, Taipei County Government, Taipei Rapid Transit Corporation, Directorate General of Highways, Taiwan Railway Administration, Keelung Harbor Bureau, ...etc. to cite a few examples of them.

With bridge data diversely stored in different ways by different institutions, problems abounded, e.g.

(1) The central-level authorities couldn’t access such data in real time, nor could they come to grasp with situations that evolved. They tended to depend on local authorities for information. More importantly, if not fatally, they couldn’t come up with proposal in time to cope with in a urgent case.

(2) Manpower and other resources thus devoted to were often overlapped resulting in misuse and/or waste.

(3) Some of the institutions were short of budget to fund a project to manage, or recruit necessary manpower to perform such duties, posing leak and/or gap .

(4) It became difficult to ensure uniformity in specifications of bridge conditions, standards, or assessment. A rationalized and efficient allotment of bridge maintenance resources hence became unlikely.

As instructed by the Executive Yuan （EY, or Cabinet）in 1995 to map out a bridge safety inspection & maintenance operations procedure in an effort to tackle such a situation, the Ministry of Transportation & Communications （MOTC）consummated “Taiwan Area Bridge Safety Management Strategy & Adoption” study in 1997. To set up a central bridge maintenance system and concurrently one that is good for the needs for all agencies is of pivotal interest. It is expected to integrate GIS, GPS, and internet technology to play an auxiliary role in the operations of bridge management, upgrading bridge service level while ensuring structural stability and safety. Bridge functions should be upheld, maintenance cost be cut back, resources be conserved, and bridge usefulness be lengthened.

Institute of Transportation & Communications (IOT) started developing “Taiwan Bridge

Management System" by the order of MOTC in collaboration with National Central University, Civil Engineering Department in November 1999. The System incorporated GIS, GPS and internet tech and emerged as an integrated nationwide bridge management system serving all institutions, i.e. MOTC, Ministry of Interior, TRA and all city/county governments. The System has proved highly helpful in bridge management by virtue of systemized, efficient and computerized approach.

2. THE SYSTEM

Functions under the System are categorized into 3 grades:

(1) central directorate level

(2) bridge directorate level

(3) bridge maintenance level

Based on such structure, they are commissioned to shape up their own strategy schemes, strategy enforcement and data collection respectively.

The System was thus designed in accordance with the 3 levels. Module was so framed to meet the corresponding demand which was further aided by client-server by means of internet tech to ascertain inter-level working relations. A user can easily enter the System by using internet browser. The server was built in the central directorate and bridge directorate levels, offering access to instantly data for transmission & setup.

Data were electronically stored in the form of media of which a back-up copy can be made in the forms of hard disk, tape, CD-ROM etc. Compared with traditionally written form, it goes faster and can be copied easily to minimize the risk of loss. The 3 levels are thus closely integrated making up a nationwide bridge management system.

The inter-operation between levels can be classified and regulated by authority delegation. When the bridge management level personnel need to check, amend, or put in bridge data in their power. For example, they can key in their account number together with PIN code thus set up to enter into connection with the server of the bridge directorate. Thereby they can check, amend, and/or key in whatever they like to. The way of authority delegation can be copied between the central directorate and bridge directorate. Such interaction is simply conducted by way of browser.

The main difference lies with the central directorate that needs to collect and analyze data for all the bridges nationwide in an attempt to command the conditions of all bridges, and for technical exploration, drawing up rules/regulations etc. Hence the policy is made and order comes from top to down. So is the direction of power delegation. Information exchange and transmission make up the nerve system, much like that of the human one. The central directorate is supposed to be the pivot, well aware of how things are going on and what, if any, goes wrong with any institutions and any bridge. That should be rendered able to react in time

so as to ensure that all bridges are under close surveillance and readiness to brace up for disaster prevention.

The users of TBMS including engineers and staff from agencies such as MOTC, Taiwan Area National Freeway Bureau, Directorate General of Highways, Taiwan Railway Administration, Ministry of the Interior, and local governments. TBMS is a web-based system that every agency can log in via web browsers if the computer is connect to the Internet. The major functions of TBMS are illustrated in Figure 1: (1) Inventory; (2) Inspection; (3) Cost Estimating; (4) Maintenance; (5) Maintenance Performance; (6) Statistics; (7) GIS; and (8) Parameters Setting.

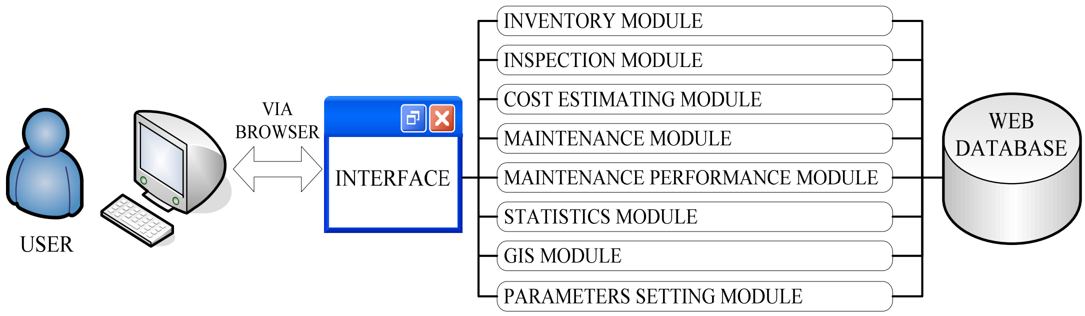

Figure 1: TBMS consists of eight functional modules.

3. BRIDGE INVENTORY FORMAT IN TBMS

At the same time when TBMS was under development, a nationwide bridge survey was conducted. The survey results were input into TBMS that include data of the inventory as well as data of the first-time inspection. Bridge inventory is the core of TBMS; all system functions would be meaningless without it. In TBMS, each bridge is characterized by 57 fields that are categorized into four types they are: (1) Management, (2) Geometry, (3) Structure; and (4) Design data, as shown in Table 1. Notably, the inventory has four or more photos for each bridge, and has a pair of GPS coordinates by which an aero-view can be obtained through the help of Google Map, as illustrated in Figure 2.

Table 1: Type of inventory data of a bridge.

Type of data	Num of fields	Instance
Management	19 fields	bridge name, bridge no., admin. agency, admin. department, county, town, road level, route, mileage, construction date, contract price, designer, contractor, location, crossover object, latest repair date
Geometry	15 fields	length, max & min width, slab area, height of pier, number of lanes, number of spans, max span length, GPS coordinates
Structure	13 fields	bridge type, beam type, abutment type, wing wall type, foundation

		type, pier type, joint type, bearing type, beam material, pier material
Design	9 fields	designed live load, acceleration, flood level, heights of bank, length of bank, heights of river bed, ground type, falling prevention device

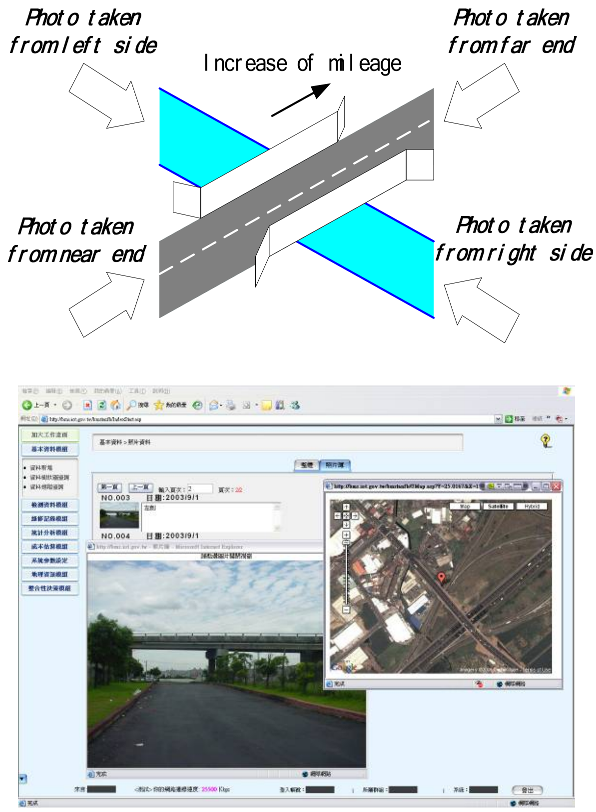

Figure 2: Four photos and aero-view of a bridge.

4. Bridge Inspection Methodology in TBMS

The methodology of bridge inspection and evaluation incorporated by TBMS is called DER&U, which was initiated by a joined effort of two consulting companies, Council of Scientific and Industrial Research (CSIR) and Join Engineering [2]. Before TBMS was officiated, there were several inspection methodologies used by different government agencies. However, after TBMS was set online and used by all the government agencies, the DER&U became the national standards for bridge inspection.

In the DER&U methodology, “D” stands for degree of deterioration; “E” represents extent of the deterioration; “R” implies relevancy to safety of the deterioration; and “U” depicts urgency for repair or renovation of the deterioration [3]. All of these indices are numerically rated on an integer scale from 0 to 4, as exhibited in Table 2. While rating the deterioration

conditions, the inspector can also input his/her personal comments his/her deems necessary.

Table 2: DER&U evaluation criteria.

	0	1	2	3	4
D	Not Applicable	Good	Fair	Bad	Serious
E	Unable to Inspect	Less than 10%	10~30%	30~60%	Over 60%
R	Relevancy Uncertain	Minor	Limited	Major	Large
U	N/A	Routine	In 3 years	In 1 years	Immediately

In the DER&U, 21 components of a bridge are identified for inspection; they are: (1) approaching embankment, (2) approaching guardrail, (3) waterway, (4) protection works for approaching embankment, (5) abutment foundations, (6) abutments, (7) retaining walls, (8) pavements, (9) superstructure drainages, (10) sidewalks, (11) guardrails, (12) scouring protection piers, (13) pier foundations, (14) piers & columns, (15) bearings, (16) earthquake brakes, (17) expansion joints, (18) longitudinal girders, (19) transversal beams, (20) decks & slabs, and (21) others. These components are defined for typical concrete bridges; other types of bridge will have slightly different fields that are currently going through an investigation.

After each of the 21 components of a bridge is rated and input into TBMS, a condition index (CI) which represents the overall condition of the bridge, can be calculated automatically by TBMS. The condition index is based on a deduct point system. Scores of deficiencies will deduct points from a perfect score of 100. In Equation (1) Ic_i is the condition of component “i”, and w_i is the weights of importance of component “i”. Equation (2) shows the calculating formula of Ic_i., In this equation, Ic_{ij} is the index of the “j” part of component “i” and n is the number of parts. Equation (3) shows the calculation formula of Ic_{ij} based on values of “D”, “E” and “R”; where “a” is an input parameter to increase the importance of “R”, usually equals to 1 or 2.

$$CI = \frac{\sum_{i=1}^{21} Ic_i \times w_i}{\sum_{i=1}^{21} w_i} \quad \text{Eqn. (1)}$$

$$Ic_i = \frac{\sum_{j=1}^{n} Ic_{ij}}{n} \quad \text{Eqn. (2)}$$

$$Ic_{ij} = 100 - 100 \times \frac{D \times E \times R^a}{4 \times 4 \times 4^a} \quad \text{Eqn. (3)}$$

5. AUXILIARY SOFTWARE OF THE SYSTEM

The System was originally structured to put all the operations processes on-line. Users, nevertheless, found that the process went extremely slowly. Frequent block-up on-line during business hours and insufficient breadth of band were to blame, it was found. They were frustrated particularly when updating data and/or transmitting photos.

To address these situations, IOT launched another plan to develop an auxiliary software in cooperation with NCU, her working partner. Given the function, users could access the System off-line from their PC.

The PC version has undergone through a series of test in April 2003 and got announced officially in February 2007.The PC version carried largely similar functions as internet version. A major difference appears in an additional up-load module which allows a user to transmit and store data off-line, if he/she so chooses. Once on-line, the module allows a user to transmit right away or at off-peak time, say early morning, e.g. if he/she so elects.

So long as a user doesn't turn off his/her PC, the data can be transmitted to master database at a time pre-specified. The user will be informed of interruption and/or failure of transmittal, if any. The transmittal will be resumed at specified time later on. A user doesn't need to re-prepare his/her data interrupted.

The PC version conquers the difficulty arising from insufficient breadth of band. It establishes a data warehouse, though smaller in scale. In the event of natural disaster or human neglect, leading to interruption, the management agencies can still access to bridge data. That is a concept of distributed database.

From the viewpoint of information security, PC version serves as a back-up and conduces to user's collection of data in relation to bridge management despite loss of data warehouse of the mainframe.

6. SUPPLEMENTARY MECHANISMS IN ASSOCIATION WITH THE SYSTEM

（1） to recruit info tech manpower for System maintenance

The internet world flings far and wide. It has proved to be a swift and convenient communication channel. Computer virus, malignant programming, and internet hackers are waiting the in the wing to steal, damage, or even paralyze the System, moreover. TBMS built in the System a firewall, data transmission coding, regular supervision, weak point scan, invasion detection mechanisms in an attempt to guarantee the security of the net environment. It is aimed at making sure that the data are kept correct.

（2） Bridge Management Operations Assessment

IOT has begun bridge management & maintenance operations assessment since 2004 at the behest of MOTC as a measure to guarantee the System formation and smooth implementation in accordance with all regulations. Items covered under this category compose of basic data listing, inspection, maintenance, manpower training program, feasibility of management system and data updating.

Results of assessment are announced for public knowledge, hopefully to cause public attention which, in turn, shores up bridge safety. Populace safety is thereby better enhanced.

（3）Training Camp for Bridge Maintenance Personnel and Circuit Education Course

IOT conducts training camp to familiarize the personnel with newly developed skills so as to improve their professionalism, service quality and efficiency. Also introduced are circuit education course based on operations of TBMS. The course is offered if and when such a need arises.

（4）Calibration of City/County Bridge Management Data- -correctitude and completeness

The System has been in place for years. There are constantly newer and newer developments, i.e. deterioration, partial cut-off, increment, renovation, no matter naturally or humanly caused. The record shall be kept fully renewed in time, to assure a complete awareness of what has happened to a bridge that possibly requires an emergency action for the purpose of disaster prevention or damage control.

IOT commenced bridge data calibration operations in 2007 to make sure that bridge record is kept updated and complete. All bridges under the jurisdiction of all city/county governments are covered. The calibration operations consist of 2 parts, data correctitude and data completeness.

By random sampling, some bridges were singled out for calibration. Assigned to the spot were experts, designated by IOT, to check the correctitude of all basic data and that of last calibration to check if anything found wrong or incomplete got righted or completed. As for completeness, we look up firstly maps available at marketplace to compare with the archives of city/county governments. We check only those bridges we find differently between. There are cases in which a map shows a bridge exists whereas the archive shows otherwise. We visit the spot where it is supposed to exist to confirm its existence or non-existence.

The calibration operations showed that the correctitude of the city/county governments stood at 91.70% on average which is fairly good while completeness showed merely 64.95% on average which requires quite something more and higher to improve.

7. APPLICATION AND UTILITY OF TBMS

（1）conducive to all institutions’ grasp of bridge conditions

All institutions base their budgeting procedures on the System for calibration and maintenance purposes.

（2）as a guide to resource allotment

The central government implemented 2 phases to renovate old, or worn out bridges for the city/county governments. Large fund was expended to demolish hi-risk bridges and concurrently erect new ones. The System has served as a competent guide.

（3）Stats are good food for long-term analysis and research

Bridge management agencies are required to update calibrated data from time to time. For academic institutions interested in bridge deterioration, degradation, increments, etc. the System poses a good, reliable, and important source.

（4）Resource consumption rationalized and bridge management streamlined

An information system on-line achieves a neat saving on cost and storage space as well. A complete and updated information which is readily accessible to is another boon for people engaged in stats, check, and supervision. It minimizes the risk of loss. Experience transfer is made easy.

8. TBMS 2009 EDITION

Eight years has elapsed since TBMS was initially brought into existence. It was revised for the first time in 2003. There are PC version and contractor version. Minor revisions took place as time passed by and users' expectation varied or changed.

A new version comes into being in May 2009 in order to

（1）streamline the bridge management operations,

（2）ensure pedestrian safety,

（3）satisfy practical need by directorate agencies.

The latest version provides warehousing service that will show which bridge has reached the phase warranting calibration and/or maintenance, aside from those functions already in place, such as displaying water level, rainfall, etc.

With the help of PDA version, some additional data as detailed as span, pier, foundation and so forth can be filled in. It renders bridge management operations ever more delicate, concise, and effective.

9. CONCLUSIONS

The System was kicked off from an academic perspective, structuring a sketch for open

discussion and brainstorming. Involved were experts and seniors in industry to review its feasibility and practicality. A series of practical tests were conducted before it was set on line.

In spite of such endeavors, there was a gap, however, between academic circle and people in practice, it was later found. The gap drew quite a flurry of criticism or even protests at the very beginning. Defects pointed at or challenged included:

（1）operators were at seas how to operate the System,

（2）some institutions had had their own and existent systems and consequently reluctant to accept the new one which, in their eyes, was anything but better,

（3）quite some functions desired were found deficient or failure to meet the users' demand,

（4）unreliable network connection,

（5）data transmission too slow.

To ameliorate and promote acceptability, IOT worked closely with NCU, its partner, to spin off into PC version, industry version, while sorting out functions. Training camp program was carried out to familiarize the users with operations. We threw the door wide open to comments and suggestions by way of bulletin board, phone call, e-mails, etc. Circuit training course was added in 2003. Anytime, anywhere, coaches were assigned to offer assistance. Barrier of mobility was totally dismantled. No limit is imposed on site, time, or frequency, in a nutshell.

We seeded assiduously. So we harvest bountifully. TBMS came up a long uphill this way, meeting with increasingly warm reception.

Looking ahead, IOT will incessantly amplify functions and heighten efficaciousness in consideration of users' demand and expectation. We will continue to consolidate demand for maintenance by other institutions so as to avoid overlapped data warehousing. Thus a combined auxiliary policymaking information is better and better bolstered.

In addition, we shall develop further automated inspection/calibration equipments to ensure calibrators' safety while we improve calibration quality and efficiency.

Toward that goal, IOT is determined to work.

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